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The classification and characterisation of extreme waves and their impact on marine energy device development

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Introduction

With increasing interest in the development of marine energy, one important research area that still needs to be explored is an improved understanding on the occurrence, propagation and evolution of extreme waves and the risk that they pose to marine energy devices.

Extreme wave events out lie traditional methods of wave of wave prediction and estimation used in ocean engineering, therefore issues can arise with structures and devices being unfit for local conditions. With this in mind the characterisation of extreme waves will prove highly useful in the development of marine structures with higher reliability. Having ascertained potential waveforms, it is then possible to asses their impacts on marine energy devices.

General definition of an extreme wave is as follows:

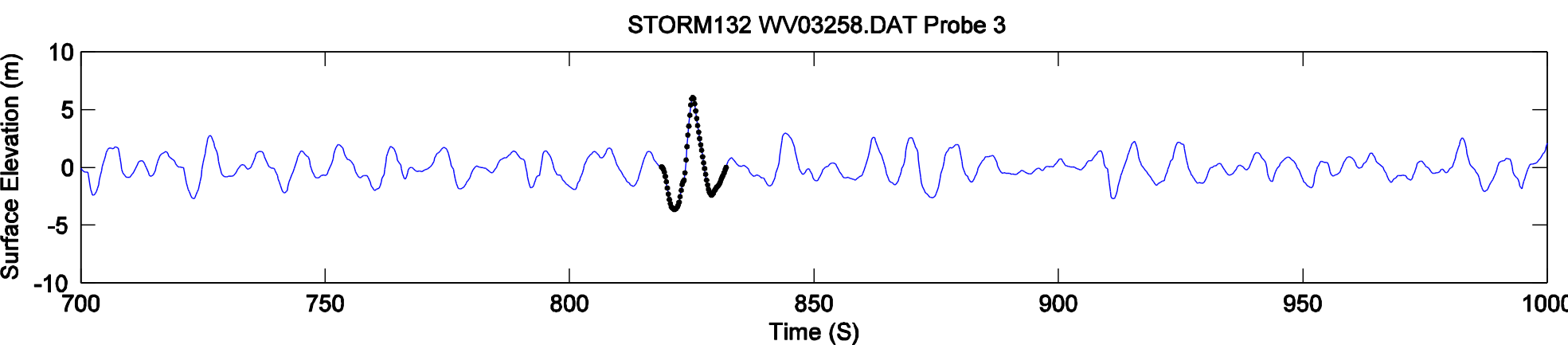
$$h/h_s > AI \text{ or } cr/h_s > CI$$

Where abnormality index AI is generally regarded as 2 or 2.2, crest abnormality index CI as 1.3, h is wave height, Cr is crest height, and h_s is significant wave height.

The aim of this work is to find a means of characterising extreme waves pertaining to marine energy devices, supplementary to directly observable parameters from measurement data. Factors that are of specific importance to devices that are not directly observable from time series data, to be investigated are:

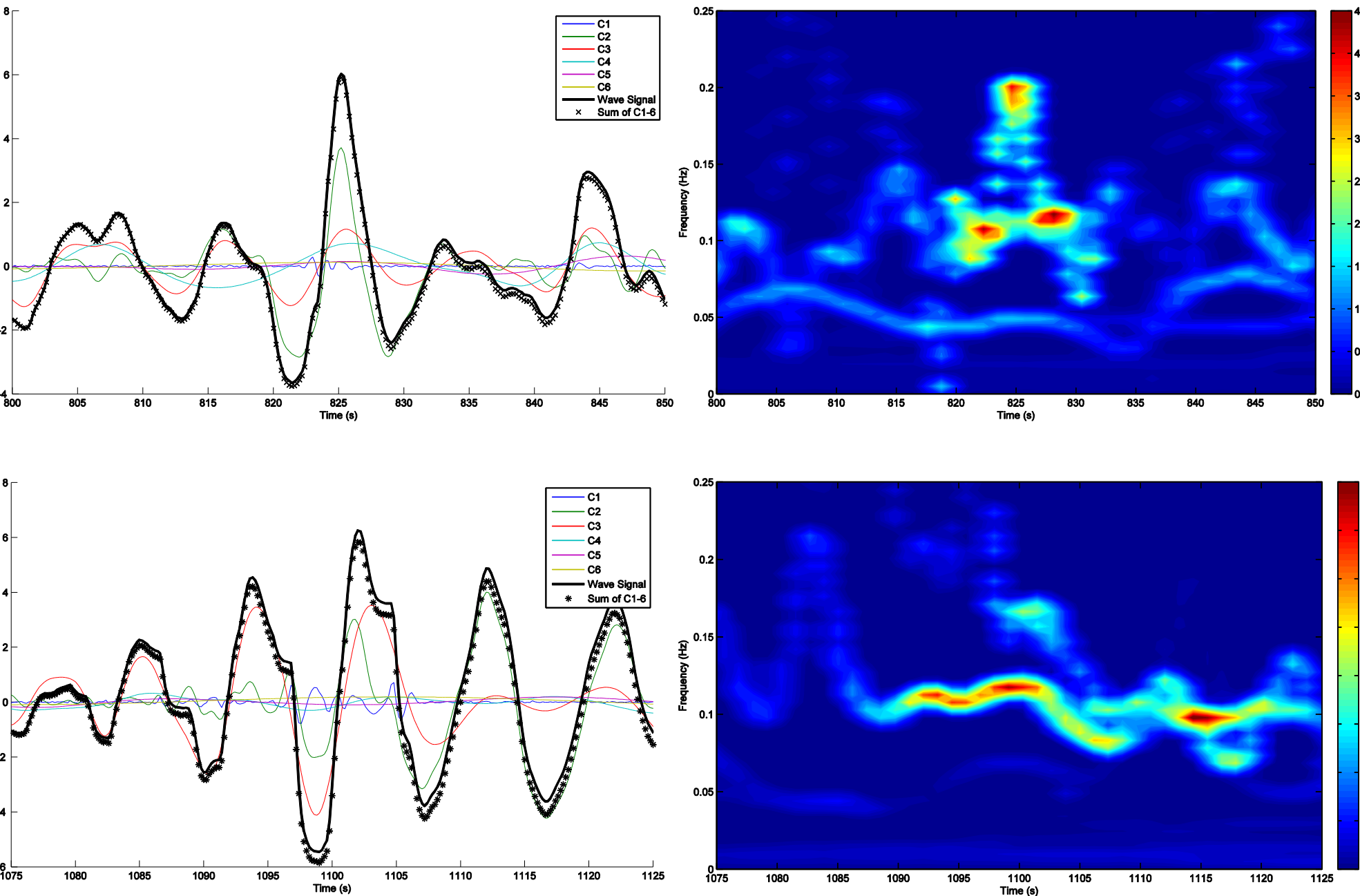
- 3D wave geometry
- Wave evolution in time and space

2D – Single Probe



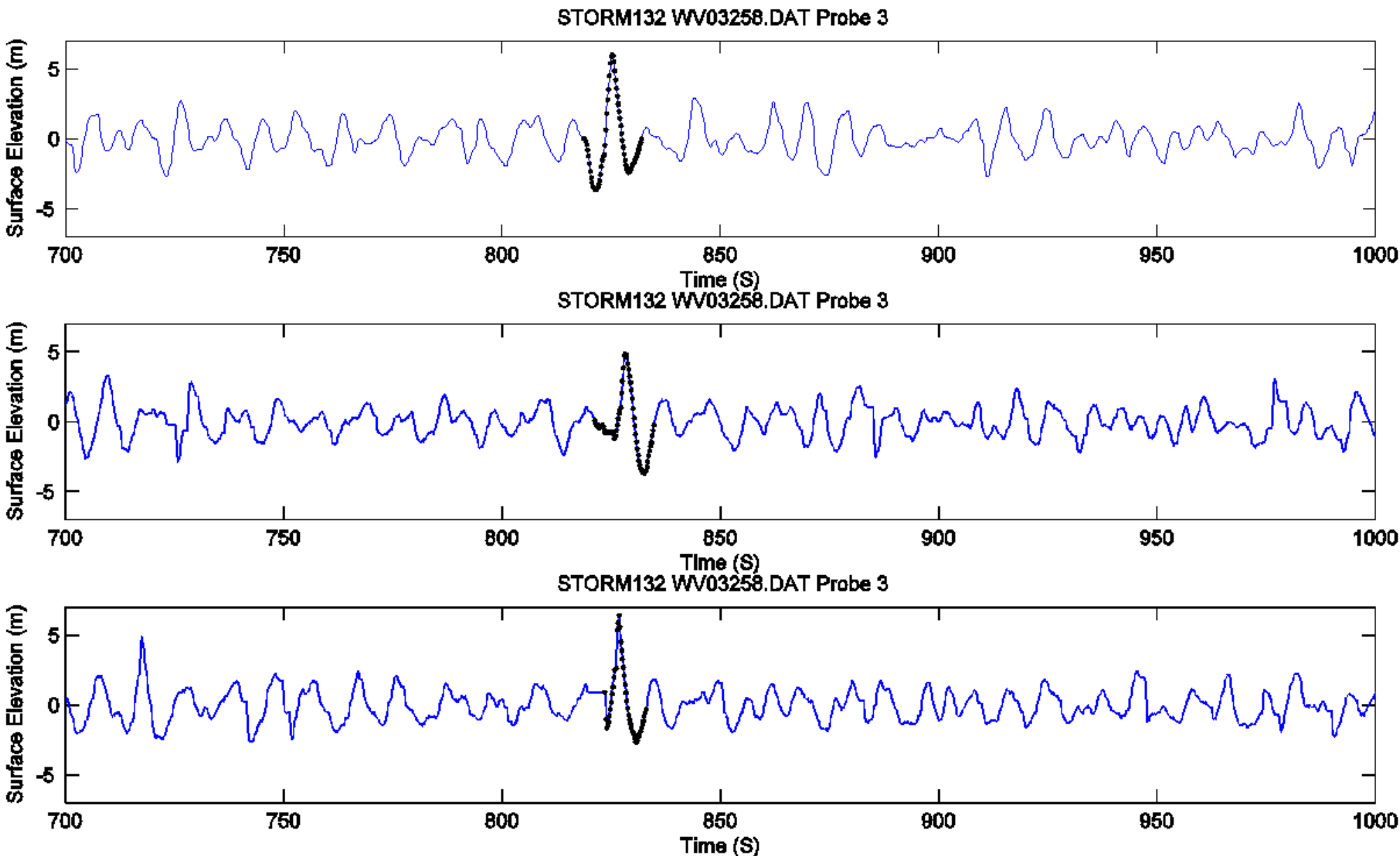
Time series data from a single probe, extreme wave highlighted

It is generally accepted that there are two fundamental mechanisms behind the formation of extreme waves, modulation instability and multi wave interaction [Xiao, et al 2013]. These mechanisms result in two characteristic wave forms, waves that appear in groups and solitary waves, respectively. The Hilbert-Huang Transform (HHT) produces the instantaneous frequency of a signal, showing the dominant frequencies that exist. The interaction of dominant frequencies highlights the responsible mechanism. Multiple dominant frequency components create a solitary wave, and a narrow banded dominant frequency creates a wave that is part of a group, shown below. Therefore, the use of HHT allows for additional information to be derived from the measurements of a single probe, as the mechanism of a waves formation affects both 3D waveform and wave evolution.



IMF's and resulting Hilbert spectrum for singular and grouped extreme waves

3D – Multiple Probes

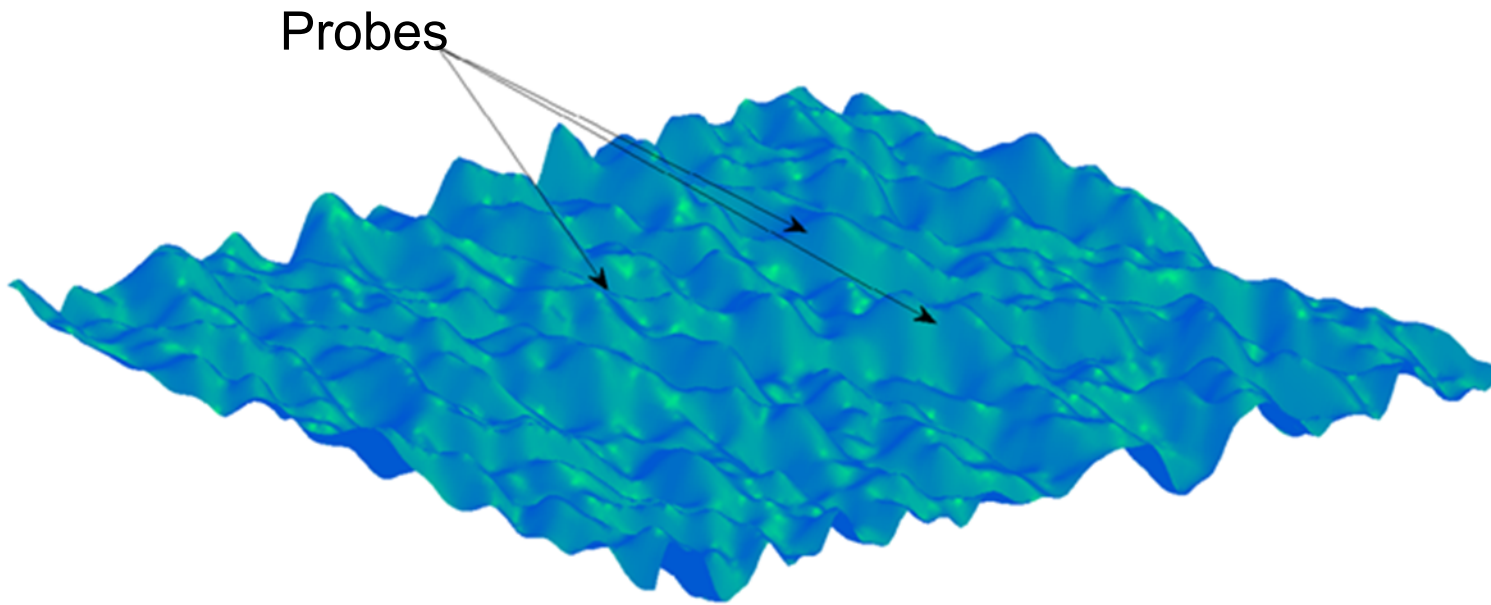


Time series data from an array of three probes, extreme wave highlighted

Focusing purely on the characterisation of 2D waveforms does not allow for a full understanding of the implications of extreme wave events. Marine energy devices possess a wide range of geometries, meaning surface elevation of a single point is insufficient information to determine the response of a device to a extreme wave. Furthermore, data from a single probe alone does not represent the entirety of a wave, hence the severity of waves may be missed or underestimated.

With the availability of multiple probe measurements it is possible to recreate a wave-field, doing this allows for the observation of the 3D geometry of waves, and their evolution ins space and time. Recreation of a wave-field will be using investigated two approaches:

- Numerically
- Experimentally

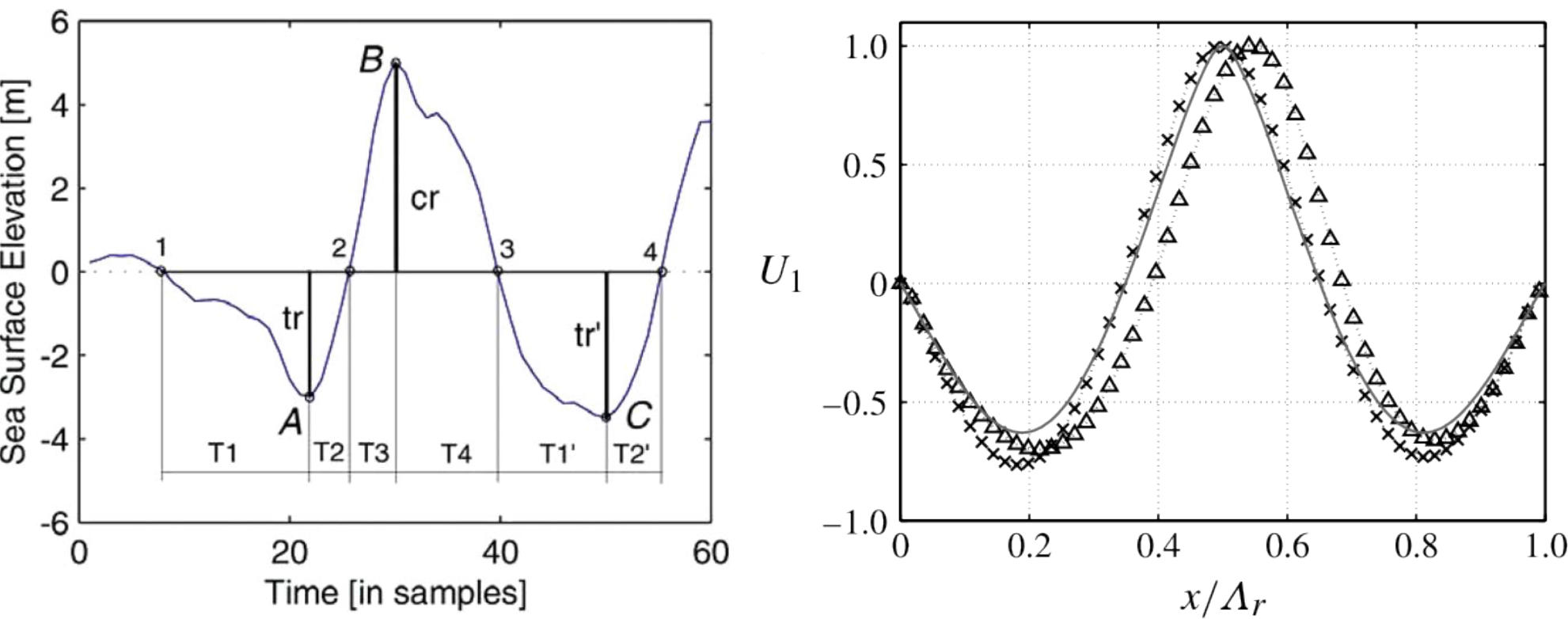


Visualisation of potential numerical wave-field reconstruction, from three probes

Characterisation

Having Identified wave mechanisms and observed the resulting geometry and evolution, characterisation can be carried out in 3D

- Steepness/asymmetry vs spectral parameters γ and ϵ plots
- Proper Orthogonal Decomposition (POD)



Examples of steepness / asymmetry and POD characterisation of waveforms , [Veltcheva & Soares, 2007], [Xiao, et al 2013]

References

Xiao, W., Liu, Y., Wu, G., & Yue, D. K. P. (2013). Rogue wave occurrence and dynamics by direct simulations of nonlinear wave-field evolution. Journal of Fluid Mechanics, 720, 357–392. doi:10.1017/jfm.2013.37

Veltcheva, A. D., & Soares, C. G. (2007). Analysis of Abnormal Wave Records by the Hilbert–Huang Transform Method. Journal of Atmospheric and Oceanic Technology, 24(9), 1678–1689. doi:10.1175/JTECH2067.1